

Feasibility assessment of anaerobic digestion technologies for household wastes in Vietnam

Đánh giá tính khả thi của các công nghệ sinh học kỵ khí xử lý các chất thải hộ gia đình ở Việt Nam

Research article

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Anaerobic digestion (AD) technologies have been utilized in Vietnam for more than 30 years with thousands of domestic small scale plants, mostly for agricultural and livestock wastes. For municipal solid waste (MSW), the development of biogas plants is far below the current high waste generation rates. The aim of this paper is to present the results of a feasibility assessment of implementing AD to treat the organic fraction of municipal solid waste (OFMSW) in Vietnam. For this purpose, an environmental analysis was performed comparing three treatment scenarios: two hypothetical AD technologies (a wet and a dry fermentation system) and the existing industrial composting facility at Nam Binh Duong Waste Treatment Complex in South Vietnam. This study sought for the technology to recover the most possible resources and energy from the OFMSW, and reduce greenhouse gas (GHG) emissions. The results were then combined with a policy review to support a holistic approach on the feasibility of these technologies in Vietnam. The outcome indicates that by implementing the dry AD system, up to 16.7 GWh of power and 14.4 GWh of heat energy can be generated annually and it can potentially save up to 8,000 Mg of CO₂ equivalent per year, presenting the highest resource/energy benefits. The performance of the wet system and composting facility present some advantages particularly if there is a previous segregation of the organic material from the rest of the household wastes. Moreover, current reforms in Vietnam demonstrate the government's interest in AD technologies, translated into the development of fiscal and financial revenues, which incentivize participation from the public and private sector. Finally, these technologies are constantly under development and have the potential to be further improved, which gives hopes that waste treatment systems can be optimized to meet the waste and energy challenges of the future generations.

Phương pháp lên men kỵ khí đã được áp dụng tại Việt Nam từ hơn 30 năm nay với hàng nghìn các công trình nhỏ chủ yếu xử lý chất thải nông nghiệp và chăn nuôi. Sự phát triển hiện nay của các nhà máy sinh khí biogas còn quá ít cho xử lý lượng phát thải cao rác thải đô thị. Bài báo này trình bày các kết quả việc đánh giá tính khả thi khi áp dụng công nghệ lên men kỵ khí xử lý phần hữu cơ của chất thải rắn đô thị tại Việt Nam. Với mục đích này, phân tích môi trường được thực hiện để so sánh ba kịch bản xử lý: hai công nghệ lên men kỵ khí giả định (một cho công nghệ lên men ướt và một cho công nghệ lên men khô) và nhà máy hiện hữu lên men hiếu khí làm phân bón compost tại khu liên hợp xử lý chất thải Nam Bình Dương ở miền Nam Việt Nam. Nghiên cứu này tìm kiếm giải pháp công nghệ để thu hồi nhiều nhất có thể các tài nguyên và năng lượng từ rác thải đô thị và giảm phát thải khí nhà kính. Các kết quả sau đó được kết hợp với đánh giá chính sách để hỗ trợ cách tiếp cận toàn diện về tính khả thi của các công nghệ này vào Việt Nam. Kết quả cho thấy áp dụng công nghệ lên men kỵ khí khô có thể tạo ra đến 16,7 GWh điện năng và 14,4 GWh nhiệt năng hàng năm và có khả năng làm giảm đến 8,000 Mg CO₂ tương đương mỗi năm, thể hiện lợi ích cao nhất giữa tài nguyên và năng lượng. Hiệu suất của hệ thống lên men kỵ khí ướt và lên men hiếu khí thể hiện một số lợi thế đặc biệt khi nguyên liệu hữu cơ cho quá trình lên men được tiền phân loại ra khỏi hỗn hợp rác sinh hoạt. Hơn nữa, các đổi mới hiện nay ở Việt Nam thể hiện sự quan tâm của Chính phủ đến các công nghệ lên men kỵ khí, thể hiện qua sự tăng trưởng tài chính và doanh thu để khuyến khích sự tham gia của khu vực công và tư nhân. Chắc chắn rằng các công nghệ sẽ liên tục được phát triển và có khả năng được cải tiến tốt hơn, mang đến cho chúng ta

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những hy vọng rằng các hệ thống xử lý chất thải được tối ưu hóa để đáp ứng được các thách thức về chất thải và năng lượng của các thế hệ tương lai.

Keywords: anaerobic digestion, composting, organic waste, biogas, environmental assessment, policy review

1. Introduction

The use of waste to energy (WtE) technologies is a current hot issue in many countries. In Vietnam, the development of biogas technologies has a relatively long history, and even when it has been largely employed for nearly the last 30 years, mostly for livestock waste treatment, the number of installed biogas plants is still limited. Regarding municipal solid waste, the first waste to energy plant in Vietnam was put into operation in 2005, producing electricity from organic household and industrial wastes (Connect et al., 2011). Since then, other than a few landfill biogas collection piping systems, no significant implementation of this technology has occurred. Instead, as it is the case in Nam Binh Duong Waste Treatment Complex (NBD), organic wastes are composted, which is, after landfilling, the most regular treatment model in Vietnam.

Having plentiful quantities of organic matter in the waste streams, the current waste and energy situation in the country encourages the use of WtE technologies to properly attend the treatment of residues as a first priority and subsequently harness the inherent potential that is currently underutilized and unexploited (Surendra et al., 2014). In Vietnam, the production of biogas from municipal wastes could cover up to 18,000 GWh, which is approx. 20% of the energy demand in Vietnam (Dornack, 2012). Furthermore, the implementation of these treatment systems supports the National renewable energy goals, which target to largely reduce the amount of GHG emissions (Chu, 2012).

1.1 Background

Since the adoption of the so-called “Doi Moi” economic reforms in 1986, Vietnam has experienced a transition from a centrally planned to a socialist market-oriented economy, leading to a strong economic growth and intensified urbanization. One of the consequences of this has been a substantial increase in the generation of urban solid waste (Nguyen & Maclaren, 2007). The proliferation of waste and the lack of proper management have been translated into serious health and environmental issues throughout the country, which are therefore of major concern. The Vietnamese population of nearly 90 million people emits an approximate amount of 15 million mega grams of waste each year; 46% of this is municipal waste (Le et al., 2013), from which the organic content sums up to 60% in most of the cases and even reaches 70% or 80% in some towns (Thanh & Matsui, 2010). This organic fraction of municipal solid wastes (OFMSW) is generally dumped into landfills or open pits, causing large releases of GHG and other environmental problems, such

as soil and groundwater contamination, which have to be urgently addressed.

In conjunction with this, the dearth of sufficient electricity for households and industries remains an increasing problem. With high urbanization rates, the energy demand is rapidly increasing up to the point that even power shortages are expected, which will only be avoided by buying more electricity from China if no previous action is taken (Connect et al., 2011). At the same time, the unceasing large fossil fuel depletion and with it emissions of greenhouse gasses by its industries, demand the adoption of new technologies and alternative sources to supply this essential resource. Accordingly, the current waste and energy situation in the country encourages the use of WtE technologies to properly attend the treatment of wastes as a first priority and subsequently harness the inherent potential that is currently underutilized and unexploited (Surendra et al., 2014). Additionally, recent studies at the Ho Chi Minh University of Industry, have determined that these wastes could achieve good energy conversion (Le et al., 2013), and obtain high biogas yields from the segregated total solid organic contents.

But how feasible is the implementation of these technologies? Which technology presents a major eco-efficiency? What is the current governance perspective on its viability? This study attempted to address these research questions with the specific targets as follows.

1.2 Objectives

The primary aim of the present study was to prove or disprove the feasibility of implementing anaerobic digestion technologies to treat solid organic wastes in Vietnam. This was achieved by reviewing the current policy frameworks and by assessing environmental factors with the specific case study of Nam Binh Duong waste treatment complex in Binh Duong Province. This study was encouraged by BIWASE (Binh Duong Water Supply Sewerage Environment Co., Ltd) and the Industrial University of Ho Chi Minh City.

This study has two objectives: firstly, based on a case study scenario, to present and describe the results obtained by the environmental and resource/energy assessment between three biological waste treatment methods. And secondly, through a policy revision, present the conclusion on the feasibility of AD from a national perspective, considering opportunities for the public and private sector, driven up by the core argument: If a change in waste management systems towards the utilization of AD technologies is truly a gain for both, the environment and the sustainable wastes' treatment.

2. Methodology

Following an integrated framework for a feasibility study of AD technologies in Vietnam, this study aimed to assess and compare the environmental impact and resource/energy balance of two state-of-the-art hypothetical biogas plants (a wet and a dry fermentation system) and the existing composting facility in NBD. This with the intention to determine the most favorable and less harmful technology for the specific local conditions and further address the viability of this technology from a national perspective.

This assessment was based on the life cycle assessment (LCA) methodology analyzing the most relevant impact categories to find out the technical and environmental feasibility of each technology and evaluate their eco-efficiency. Moreover, a material flow analysis was performed, seeking to measure energy and material flows for information on the optimal use of resources. The analysis was carried out based on field observations, literature review, and data provided by BIWASE, the Industrial University of Ho Chi Minh City and two specialist German companies hereby addressed as Company A (AD1) for the wet fermentation system, and Company B (AD2) for the dry fermentation system.

2.1 Objects under investigation

The selection of the analyzed biogas plants technologies was made taking as an example two German treatment systems that have proven to be efficient. These plants present values according to previous experiences of Company A and B, with similar conditions than in Vietnam.

Inputs. All substances currently brought into the household waste facility at NBD and eventually to the composting facility were contemplated among system inputs. These consist in two main categories: Energy and resources. The energy systems considered were: Diesel, electricity and heat. The resource materials were the typical wastes that are treated in the existing waste facility, together with the water resources used. Table 1 shows the types and approximate quantities of waste that are treated and processed every day at this facility.

Table 1: Household waste inputs to NBD

Material inputs		
Type of waste	Mg/d	%
Household waste total	420	100
Organic fraction	255	61
Food and fruit waste (OM)	155	60 OF
Lignin and raw organics	50	20 OF
Impurities (mostly *HCF)	50	20 OF
Plastic, metals, glass	25	6
Landfilled material	140	33

*HCF: High Calorific Fraction

Composting facility. The treatment and utilization of the OFMSW in NBD is currently carried out throughout the household waste facility by BIWASE. The system mainly

consists of six major process stages which are shown in Figure 1 and are: Reception of household waste, mechanical screening, fermenting storehouse, turning windrows, refining humus compost and storage and marketing of products.

Wet fermentation plant. The wet AD waste treatment method consists of two main steps: The hydromechanical pretreatment and the AD of the segregated organic fraction. Considering that wastes are not source segregated, an extra sorting procedure, a so-called waste pulper, is implemented to separate recycling materials and larger impurities. Once the organic material is free of any disturbance objects and thoroughly homogenized, it is stored in a suspension buffer tank until it is fed into the digester. Here, the organic material is treated under mesophilic conditions (between 35 to 38 °C), for a period of generally 21 days. The main product, biogas obtained from the digestion operation, is then processed into the gas engines and produce heat and electricity, which could then be fed into the national grid system. In the case of the digestate, it could be composted.

Dry fermentation plant. The dry fermentation proposed method is based in a technology mainly developed to address municipal waste management issues and generate energy. This waste treatment method targets to achieve the full potential of organic waste or biomass arising from municipal facilities through a single step: dry batch fermentation system. The process undertaken is distinguished by energy generation from biomass with garage-shaped fermentation containers. Generally, multiple of these digesters are combined into one block and can be operated with time lags in batch operation, which is the case of this particular study. This enables for both continuous available treatment capacities without the necessity of long-time storing, as well as relatively constant gas production concerning quantity and quality.

2.2 System boundaries

The boundaries for the systems assessed under this case study are shown in Figure 1. The main energy and material flows limits have been identified by the areas assumed to have major influence on the composting and biogas treatments, acknowledging the complexity of the overall system. The systems boundaries include the input of waste, diesel, heat, water and electricity, and four major product outputs: Electrical and heat energy, water and humus compost; but no the transportation and final use of them, avoiding problems in boundary definition. Additionally, environmental GHG emissions were also included.

2.3 Assumptions and limitations

Within the established system boundary, the following assumptions and limitations were applied:

Systems similarities. For the three studied systems the amount of organic waste to be processed was considered 255 Mg per day. The mechanical segregation of HCF and raw materials is to be admitted the same for the three scenarios and hence, their treatment is disregarded.

Transportation. Collection and transportation emissions were not included due to the fact that the driving distances have a considerable large variance range from 1 km to up to 55 kilometers maximum. Collection, disposal and pre-treatment of wastes were considered the same for the three cases.

Impact categories. Possible impacts for a detailed LCA of waste treatment systems such as noise, odors, dust, acidification potential, toxicity potential, ammonia emissions, or eutrophication potential were hereby not included.

Calculations. GHG emissions savings by the proposed treatments, which will otherwise be produced by biomass decomposition via landfilling methods, are not included in this estimation, considering the complexity of their calcu-

lation, and the fact that the resulted number will not significantly affect the final comparison.

2.4 Impact categories

The impact categories selected for this study are GHG emissions and global warming potential, energy usage, and material and nutrients flow. It is assumed that they cause the most relevant environmental impacts, caused by the emissions and outputs of the suggested treatment systems and the utilization of resources. The analytical calculations were carried out choosing objectively the unit indicators and parameters to be analyzed, and to determine the materials and energy input/output, and CO₂ savings ratios.

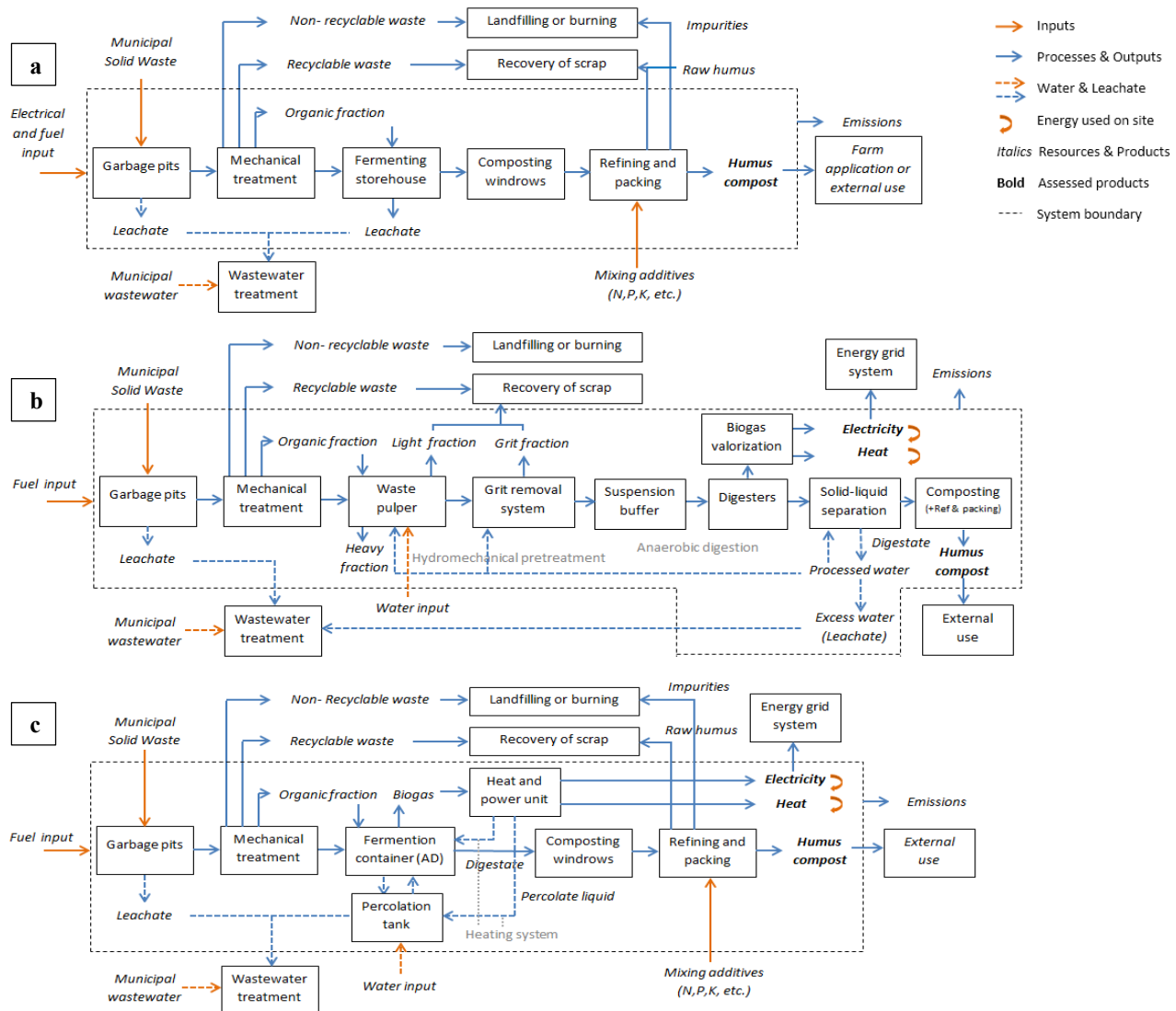


Figure 1: Overview of the waste treatment systems with relevant material and energy flows: (a) composting facility; (b) wet fermentation treatment; (c) dry fermentation treatment

2.4.1 Mass flow and nutrient balance

The mass flows were obtained using a standard Material Flow Analysis (MFA) as a tool to methodically assess the stocks and flows of materials within the delimited system on an annual basis. The most relevant substances and products originated throughout the treatment processes

are: humus compost, raw materials, the high calorific fraction and the water used and released.

2.4.2 Energy balance

In order to evaluate the energy balance of the three treatment techniques proposed for this study, a base common scenario was created where energy needs and production

were obtained, estimated or determined for the operations required to run the processes. This base scenario was developed to evaluate and compare the energy balance and efficiency of the inputs and outputs of diesel, electricity and heat. Energy flows were identified, quantified and analyzed within each system, and through the following formula (Eq. 1), the energy input/output ratio was obtained, which helped to realize the energy efficiency of each system.

$$\text{Energy } \frac{i}{o} \text{ ratio} = \frac{\text{Energy inputs}}{\text{Energy outputs}} \quad (1)$$

2.4.3 Emissions and global warming

For this impact category, the greenhouse gases with major impact, including carbon dioxide, methane and nitrous oxide, were analyzed considering their conversion before they are released, and the replacement of energy produced by fossil fuels. For this purpose, the following calculations were carried out:

- Direct CO₂ equivalent emissions due to energy consumption and fugitive gases;
- Saved CO₂ equivalent emissions due to energy production;
- The overall saving potential and CO₂ savings ratio.

The results illustrate the total CO₂ equivalent emissions for these gases. Figure 2 shows the emissions and savings considered to calculate the total emissions balance. The savings potential and the CO₂ savings ratio (R) were calculated to compare the greenhouse gas emissions between the proposed scenarios, as follows (Eq. 2-3):

$$\text{Saving potential (SP)} = \text{CO}_2 \text{ saved} - \text{CO}_2 \text{ emitted} \quad (2)$$

$$\text{CO}_2 \text{ savings ratio (R)} = \frac{\text{CO}_2 \text{ emitted}}{\text{CO}_2 \text{ saved}} \quad (3)$$

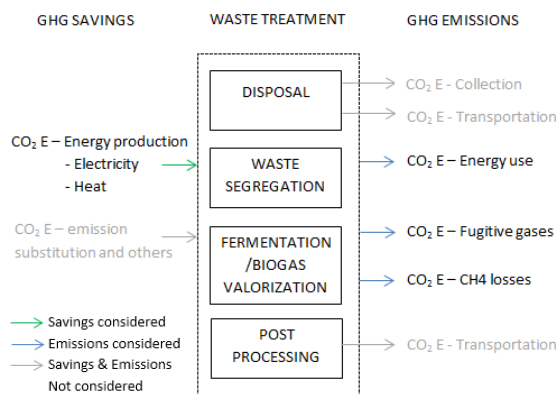


Figure 2: Emissions and savings of CO₂ equivalent considered in this study

3. Results and discussion

3.1 Mass flow and nutrient balance

Materials and energy accounting allowed for the early selection and recognition of the relevant materials and flows that were analyzed, attempting to follow a straightforward environmental assessment.

In Table 2 and Figure 3, the considerably large water utilization by the wet fermentation treatment in comparison to the other two scenarios can be observed. The water demand by this system is approximately 40% of the total organic fraction (90,000 Mg/a), which accounts for 6.6 more water needed as by the composting facility, and even 144 times more than the dry system, being the dry method the most water efficient with only 250 m³ water demand per year.

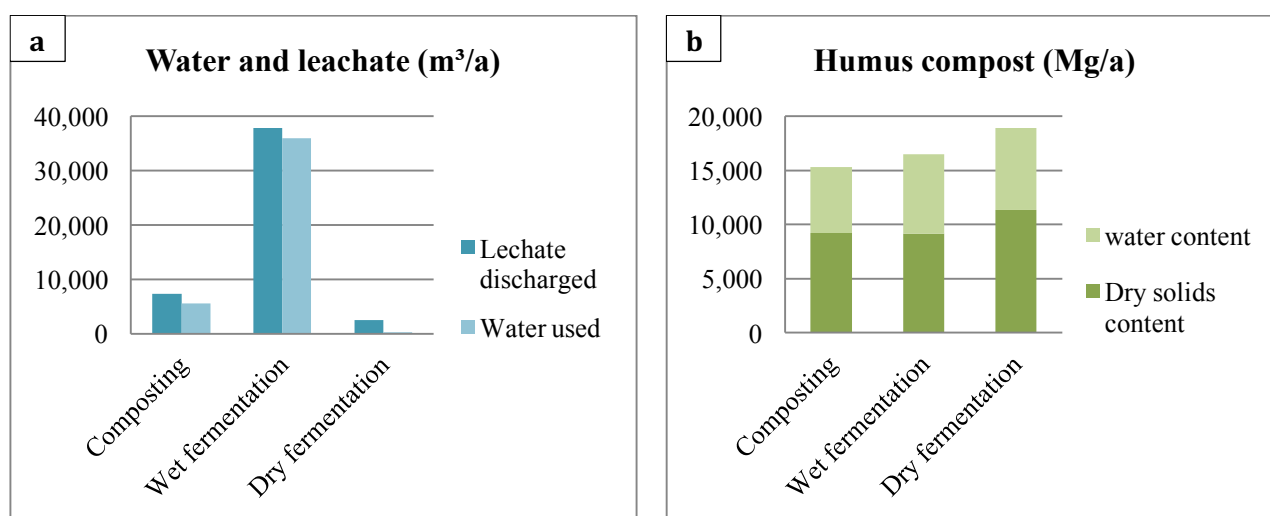


Figure 3: (a) Water consumed and leachate discharged; (b) Humus compost produced

Table 2: Materials discharged and produced: Water and leachate, raw organics, high calorific fraction, digestate material and humus compost

	Water		Lignin and raw org.	Impurities (HCF)	Digestate	Compost
	Leachate (m ³ /a)	Water used	(Mg/a)			
Composting	7,300	5,500	18,000	14,000	-	15,300
AD1	37,800	36,000	18,000	14,000	36,000	16,500
AD2	2,500	250	18,000	14,000	81,000	18,900

Currently, as shown in Figure 3(b), the total humus production at the composting facility is about 15,300 Mg/a (42 Mg/d \pm 10%). For the dry system, it is estimated that 52 Mg per day could be potentially converted into compost, which is 23% more. The wet system estimates to produce 8% more than the composting facility (45 Mg/d).

This refined humus compost is then further processed to produce organic fertilizers. In this line, the overall relative low production of humus compost in NBD is mainly attributed to the fact that without a source segregation of the organics, the mechanical sorting becomes inefficient, and because the composting processes of almost 70°C produces high water evaporation rates.

3.2 Energy balance

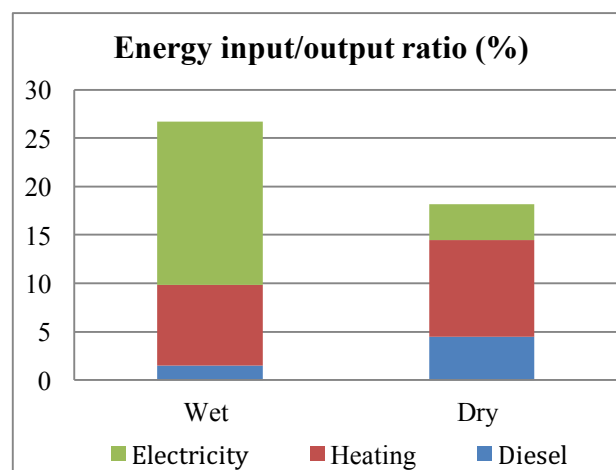
Table 3: (a) Energy consumed and produced in MWh: diesel, heat, electricity and energy input/output ratio; (b) Saving CO₂ emissions potential and CO₂ savings ratio

a	Diesel	Heat			Electricity			E-ratio
		Consumed	Produced	Available	Consumed	Produced	Available	
Composting	876	-	-	-	1,296	-	(-) 1,296	-
AD1	603	3,400	20,513	17,112	6,820	20,000	13,180	27%
AD2	1,622	3,600	18,000	14,400	1,320	18,000	16,680	18%

b	CO ₂ emitted	CO ₂ saved	Saving potential		Ratio
				Mg/a	
Composting	7,929	-	(-) 7,929		-
AD1	8,662	16,341	7,679		53%
AD2	6,535	14,550	8,015		45%

To evaluate the energy balance and efficiency by the analyzed three systems, the energy input/output ratio was calculated. This number is the percentage of energy consumed out of the total energy produced by each system.

From a general energy demand perspective, composting is naturally the most efficient option since it requires much less energy for the waste treatment processes. On the other hand, as presented in Figure 4, the wet treatment performs better for diesel and heating input/output ratios. However, due to the high electricity demands by this system (6,820 MWh per year), dry fermentation resulted to be the most energy efficient method, with only 18% of the energy produced necessary for the internal demands, in contrast to 27% by the wet system.

**Figure 4: Energy input/output ratio**

Hence, considering that the proposed anaerobic technologies present other general energy benefits (such as high methane production rates for the wet treatment, or low power needs for the dry systems, among others), it can be clearly concluded that the energy balance is favorable for the AD technologies and in particular to dry fermentation techniques. This technology consumes much less energy

out of the total energy amounts obtained from the produced biogas. Ultimately, it can be concluded that implementing the dry fermentation system in NBD will generate up to 16.7 GWh and 14.4 GWh of available electricity and heat energy per year, respectively. Wet treatment methods could potentially perform better if there was a previous source separation to handle only the uncontaminated organic matter fraction.

3.3 Greenhouse gases emissions

For the CO₂ footprint, the greenhouse gases emitted by the direct consumption of energy, together with the fugitive emissions from the aerobic and anaerobic fermentation processes were calculated. In the case of the emissions saved, the CO₂ equivalent represents the possible CO₂ eq. savings if this energy was produced by traditional fossil fuel depleting means. Furthermore, in order to assess and compare the greenhouse gas mitigation efficiency for the analyzed scenarios, the CO₂ savings potential and CO₂ ratio were determined. As can be seen in Table 3(b) and Figure 5, the total amount of CO₂ eq. emitted and tentatively saved is larger for the wet fermentation system. Nevertheless, the overall savings potential is slightly higher for the dry system. In other words, the dry method can potentially save up to 336 more mega grams of CO₂ eq. per year to be released than the wet system. The obtained CO₂ ratios also demonstrate the better efficiency of the dry system, indicating an approximate 8% difference to the wet system, i.e. that the CO₂ eq. emitted by this system is 45% of the total it can save; in contrast with 53% for the total of the wet treatment.

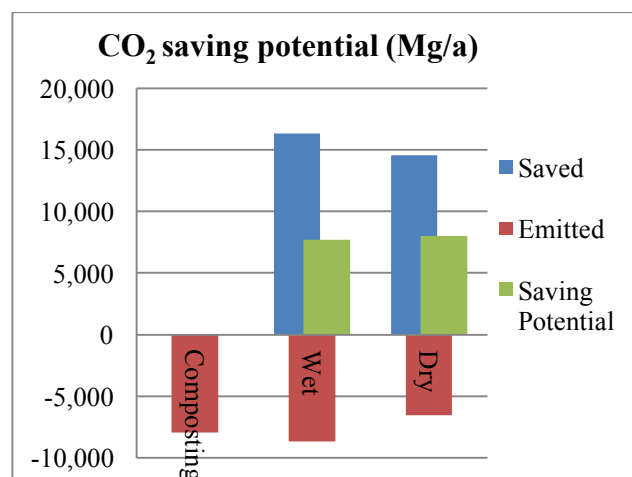


Figure 5: Overall potential for CO₂ emissions saving

3.4 Policy review; public and private sector participation

From a governance perspective, Vietnam has high potential for WtE projects. Since the new economic reforms in 1986, the rapidly increasing generation of wastes, large energy demands and climate change consequences urged local governments to implement better energy and waste management practices. For this, WtE technologies have been recognized as an important approach to attend these issues. The last policy updates and reforms demonstrate the government's interest on energy production from organic wastes and reduction of environmental impacts,

implementing new management strategies. The "Green Growth strategy", "National Master Plan for Power Development 2011-2020" and the "National Solid Waste Management 2025", are examples of recently established legal frameworks that are currently being implemented. Regrettably, the efficacy of such reforms has been rather slow mostly due to lack of strong institutional system, large investment needs, and lack of public interest.

Furthermore, these recent reforms have been translated into the development of fiscal and financial incentives, which support investors and promote biogas technologies as a profitable waste treatment method. Examples of these incentives are: the exemption of taxes, loans, land use benefits, fixed electricity fed-in tariffs, among others. These benefits, added to the well-known returns from energy and fertilizer production. Additionally, carbon credits from the Clean Development Mechanism offer in many cases sufficient revenues to cover the cost and be profitable (Karagiannidis et al., 2009). However, it is difficult to draw any far-reaching general conclusion on economic feasibility of anaerobic digestion since the costs are significantly also affected by each system type, local conditions and organic fraction quality. Not at least, it is an investment for about 20 to 30 years of operation, which needs clear planning reliability for the investors on the expected incomes.

Furthermore, according to these findings and the policy review performed, the implementation of anaerobic digestion and further materialization of these technologies in Vietnam, may consider the following recommendations:

- The safe treatment of wastes should be seen as the main objective of anaerobic digestion technologies, and secondly the economic benefits.
- Attend the institutional flaws: Establish well-functioning monitoring and transparent systems should be a high priority at national and local levels.

Regarding the economic feasibility of such projects, it is recommended that a detailed cost analysis is carried out for each case; and legal action is taken to increase the gate fees at disposal sites.

4. Conclusion

As a main result of the environmental and resource energy assessment performed, it will be technically and environmentally feasible to implement a box-shaped dry fermentation biogas plant for an input of approx. 90,000 Mg of organic household waste per year at the Nam Binh Duong Waste Treatment Complex. Thus, a change in the actual waste management methods for this technology will be truly a more sustainable practice. Accordingly, among the well-known advantages of these technologies, a number of specific benefits were detected, as follows:

- This technology could largely reduce the amount of water consumed and waste water generated by the current composting processes, using only 250 m³ per year.

- It is estimated that 51 Mg per day of valuable humus compost could be produced, which is approximately 23% more than the currently produced.
- Up to 16.7 GWh and 14.4 GWh of available electricity and heat energy could be generated per year, respectively.
- Up to 8,000 Mg of CO₂ equivalents per year released by fossil fuel means could be saved, achieving large mitigation effects on GHG emissions.
- Resistance for utilization of organic wastes with large quantity of impurities, raw materials and extraneous materials, making it a robust and sophisticated method.

To sum up, the use and promotion of anaerobic digestion technologies in Vietnam is technically and environmentally feasible and has a high potential, presenting a series of favorable use of resources and energy, and high greenhouse gas mitigation rates, especially for dry fermentation methods compared to other treatment technologies for the current level of technology. It is a long term sustainable solution, which helps to:

- i. Create safer waste treatment systems;
- ii. Match energy demands supplying clean energy;
- iii. Obtain attractive revenues for the private and public sector, and;
- iv. Simultaneously protect the environment.

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